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LABOR MARKET IMPERFECTIONS AND
THICK MARKET EXTERNALITIES FROM INNOVATION

Daron Acemoglu

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massachusetts
institute of
technology

50 memorial drive
cambridge, mass.02139

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Daron Acemoglu

Department of Economics, E52-371
Massachusetts Institute of Technology
Cambridge, MA 02139

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Abstract

When labor market imperfections are important, workers (and firms) do not receive their full marginal product. This is shown to imply that the adoption of an innovation that increases the non-firm specific marginal productivity of a worker creates a positive externality on other firms. The presence of this externality can lead to a multiplicity of equilibria whereby in the inferior equilibrium innovation is not profitable because the workforce is untrained (unskilled). This mechanism illustrates how labor market conditions influence investment and innovation activity thus offering new links between unemployment and growth. These links also imply that when the entry decisions of firms are endogenized a further thick market externality is created since entry, by reducing unemployment, makes investment and further entry more profitable. Finally when firms are allowed to choose the timing of their innovation, free-rider effects are introduced and the Pareto preferred equilibrium disappears.

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1) Introduction

Innovations and investment in new technology are likely to be among the major channels of growth in the economy and cyclical changes in these activities are often thought as a major driving force of economic fluctuations (e.g. Schumpeter (1939)). When a firm's incentives to invest or to innovate depend on the actions of other firms in the economy, a multiplicity of equilibria in which expectations become self-fulfilling is possible and economies with similar fundamentals can exhibit vastly different growth and cyclical behavior.

Two mechanisms that introduce strategic complementarities/thick market externalities in investment decisions have been extensively studied in the literature. First, in monopolistically competitive markets, the demand for a firm's product may depend on the production level of other firms implying that a given firm is more likely to produce (or invest), when other firms do so. These aggregate demand externalities have been investigated by Shleifer (1986), Blanchard and Kiyotaki (1987), Murphy, Shleifer and Vishny (1989). Second, productivity of individual investment may be increasing in the amount of aggregate investment, for instance because productive information spreads between firms. This type of technological externality has been analyzed in different contexts by Romer (1986), Durlauf (1991,1993), Acemoglu (1993). It is also possible to classify the search externality model of Diamond (1982) in this category, as the thick market externalities in Diamond's economy is generated by the social increasing returns embedded in the search technology.

With the possible exception of Diamond's contribution, labor market interactions are not central to this literature. This paper argues that interactions in the labor market can be a source of an important additional externality. Most innovations are associated not only with an increase in the productivity of physical capital but also in the human capital of workers. It therefore becomes important to determine who would benefit from the future revenue stream provided by the increased human capital of workers. Additionally, the propensity to innovate is obviously a key ingredient in economic growth and the influence of the organization of labor markets on growth is an important theoretical and practical concern that has attracted very little attention (although the implications of growth on the equilibrium rate of unemployment have recently been studied by Aghion and Howitt (1992) and Bean and Pissarides (1992)).

In this paper we analyze investment in new technology that requires the training of workers. This complementarity between physical and human capital can be technological in nature but it can also be interpreted as the workers learning to adapt to new organizational forms. We will additionally assume that there always exists a positive probability that the

employment relation will come to an end and either the worker or the firm will have to look for a new partner (see micro evidence suggesting the presence of high uncertainty for jobs, e.g. Leonard (1987), Davis and Haltiwanger (1990,1992), Blanchard and Diamond (1989,1990)).

Despite such large reallocations and uncertainty concerning the future of the employment relation, complete markets in particular competitive labor and perfect credit markets, ensure that property rights on the increased revenue stream due to the higher human capital of workers are efficiently distributed, leading to first-best innovation and training decisions. Efficiency would require the worker to make a payment to the innovating firm equal to the present value of the increase in his future earnings, which, in the presence of complete markets, coincides with present value of the social benefit from training (Becker (1975)). However when labor market frictions are important, for instance due to costly search, the worker will anticipate that he may not receive his full marginal product in his future relationships and therefore will pay the firm less than first-best subsidy, leading to undertraining and underinvestment. It is important to emphasize that this result arises despite the fact that the firm and the worker are allowed to write complete contracts and the worker has access to unconstrained borrowing opportunities. This mechanism not only leads to less than optimal training and innovation incentives, but also introduces a strategic complementarity between the innovation decisions of different firms: whilst an individual firm faces higher private costs due to a lower training subsidy from its workers, it also anticipates being able to extract higher surplus from high human capital workers in future bargains if it possesses the new technology. Thus the higher is the proportion of trained workers in the economy, the higher is the profitability of new physical capital to an individual firm. Put differently, the higher is the number of firms that adopt the innovation and train their workers, the more profitable it becomes for each firm to do so.

This is a new source of externality affecting innovation and training incentives, distinct from those outlined above. It is caused neither by technological externalities nor by interactions in the product market and is strong enough to lead to multiple Pareto-ranked equilibria. In the Pareto-dominated equilibrium, innovation is low because the workforce has insufficient human capital, a direct result of low innovation incentives. We also show that the higher is unemployment in the economy (or in the relevant sector), the lower is the marginal profitability of innovation which implies that high unemployment will be associated with slower growth. Consequently, more serious imperfections in the labor market can lead to slower growth via two channels: first by creating a larger wedge between social and private productivity and second by increasing unemployment. In search models, unemployment is usually decreasing in the

number of firms that enter the market. The mechanism identified in this paper, which makes profits decreasing in the level of unemployment, implies that another novel strategic interaction is created by the entry decisions of firms; as more firms enter, unemployment is reduced and investment and further entry become more profitable. Finally, when we allow firms to choose the timing of their innovation activity, additional free-rider effects are introduced in the innovation decisions and destroy the favorable equilibrium, thus intensifying the inefficiency.

The plan of the paper is as follows. The next section explains the basic externality in a two-period model and discusses the empirical relevance of the mechanism that is proposed in this paper. Section 3 considers the continuous time infinite horizon analogue of this model. Section 4 closes the model of section 3 and discusses the links between unemployment and growth. Section 5 illustrates the free-rider effects by allowing firms to choose the timing of their innovation and finally section 6 concludes, while the appendix contains all the proofs.

2) Search in the Labor Market and Thick Market Externalities

a) A Two-Period Example

Consider a two-period economy consisting of a continuum of firms and workers with equal measure normalized to 1. Workers and firms are matched one to one so that there is full employment. All agents are risk-neutral, the discount rate is set equal to zero and the product market is competitive. Each firm can initially produce y units of the single good of this economy and at the start of the first period it has an option to invest in a new technology that will increase the output of its production process to $y+\alpha$ in both periods. However, workers in this economy do not possess the necessary human capital to work with this new technology and hence they need to be trained in order for the new technology to be productive. Note that the increase in the output of the firm is independent of the number of firms that adopt the innovation. This assumption rules out both technological and aggregate demand externalities as the revenue of the firm is independent of the number of firms investing in the new technology. Although restrictive, this enables us to emphasize the new mechanism suggested in this paper.

The installation of this technology is assumed to cost δ. Although there is evidence suggesting that new investments are often bulky (e.g. Cooper and Haltiwanger (1993)), our argument does not depend on this aspect which we only use to simplify the analysis. The training cost for each worker is c, which is assumed to be less than the incremental output; α. While the innovation opportunity is only available at the start of the first period, an untrained worker can be trained in either period. The human capital that the worker acquires will in general have firm-

specific and non-firm-specific components. The firm-specific part of this human capital is not our concern in this paper as it will not lead to the effects discussed in the introduction as long as comprehensive contracts can be written between the firm and the worker (e.g. Becker (1975)). Since the adoption of a new technology across the economy is considered, it is plausible to assume that some part of this human capital is general: a worker who can run a new machine would be able to work with an identical machine owned by a different firm. To simplify the analysis, we assume that all the human capital that the worker acquires is general.

Crucial to our mechanism is the inability of workers and firms to make their relationship continue as long as they desire; unavoidable separations are possible. Empirical evidence suggests separations and job destruction to be an integral part of the labor market (e.g. Leonard (1987), Davis and Haltiwanger (1990,1992), Blanchard and Diamond (1990), Blinder and Krueger (1991)). For instance Blanchard and Diamond (1989) report that close seven million workers move jobs per month and Leonard (1987) shows that even in the absence of sectoral reallocation, as much as 4.5% of all workers are separated from their jobs every month. We model this situation by assuming that firms face idiosyncratic shocks (as evidenced by Davis and Haltiwanger (1990,1992)) at the end of the first period and as a result disappear (shut-down) with probability d. Similarly workers may have to leave this firm for instance die or move to another region, sector or firm[1]. To simplify the analysis we assume this to happen with probability d for each worker as well. These two assumptions capture the fact that firms and workers cannot make sure their relationship will have a predetermined length, but instead the actual duration of the relationship is determined by stochastic events. In general there will also be new workers and firms who come to the market in the second period, but again to keep this example as simple as possible we assume that there are no new arrivals.

First consider the case where the labor market is competitive and workers have access to perfect capital markets. In the second period, labor will be traded in a Walrasian market and a trained worker will receive an amount c more than an untrained worker, since this equals the saving the firm makes by hiring a trained rather than an untrained worker (it is assumed that firms know whether a worker is trained or not, implying that competitive bidding will allocate the "right" workers to the "right" firms as trained workers are more valuable for firms that have

[1] However we are not interested in voluntary quits caused by a better wage offer because such a move can be made sufficiently unattractive for the worker by an exit fee. Yet if the worker learns over time that he is not happy with this firm or that his talents will be put to better use in another sector or firm, an exit fee will not solve the problem, see footnote 3.

adopted the innovation). In the first period, workers realize that if they are alive, they will obtain an additional c in the second period. Thus each worker would be willing to subsidize their firm for the increase in the present value of his future earnings by partly paying for his training, for instance by taking a wage below his marginal product in the first period or by borrowing from the perfect capital markets and posting a bond. The increase in the present value of the worker's earnings is equal to (1-d)c as with probability d he will not be in the market. On the other side of the market, if it invests, the firm will increase its revenue by α, this period and by α-c, next period (as it will have to pay a higher wage to get a trained worker or hire an untrained worker and pay for his training). But this second period return will only accrue to the firm if it is not destroyed. Thus its present value is $(1-d)(\alpha-c)$. It will be profitable to invest only when the sum of the increased revenue this period, the expected value of higher revenue next period and the subsidy paid by the worker exceed the current cost which is $\delta+c$. Thus investment is profitable iff $(2-d)\alpha \geq \delta+c$, also the optimal decision rule for this economy. Therefore despite the uncertainty concerning the future of the employment relation, the competitive markets allocate resources efficiently because after separation both parties obtain their full marginal product.

Let us now turn to a labor market with matching frictions. In the second period workers without a firm and firms without a worker will search for partners and get matched together. However frictions imply that after the initial match neither party can costlessly change partners. Further as we are considering a two-period model, it is not possible to turn down a match and look for a better partner, thus a trained worker will accept a job in which he cannot make best use of his skills. This is however not crucial to our argument (see below). This imperfect mobility creates a surplus between these pairs and ex post bargaining over this surplus will determine wages. For simplicity let us assume that the match-specific surplus is equal to the whole surplus and wages are set to a proportion β of this. Also to demonstrate that it is labor rather than capital market imperfections that drive our results, we assume that workers have access to a perfect capital market and enforceable contracts between the matched pair can be written. These two assumptions also imply that a simple reallocation of property rights between the firm and the worker cannot solve the problem.

This economy is analyzed backwards starting from the second period. If a trained worker is matched with a firm who adopted the innovation in the first period, the total surplus will be $y+\alpha$. Thus, the wage paid to a trained worker is $w^t=\beta(y+\alpha)$. On the other hand, when an untrained worker is matched with a firm possessing the new technology, the total surplus is y

if the firm does not train the worker. The assumption that firms and workers can write complete contracts implies that the firm should get the marginal return to its training decision; thus the untrained worker receives $w^u = \beta y$ (incidentally, we get exactly the same result if $w^u = \beta(y+\alpha-c)$). Finally if the firm did not innovate in the first period, then the total surplus is equal to y and the wage that it pays to its worker, irrespective of whether he is trained or not, is given by $w^n = \beta y$. Now assume that a proportion ϕ of the firms are expected to innovate. Since no new firms arrive and firm death is not conditional upon whether the firm has the new technology or not, the proportion of firms looking for a match in the second period will also be ϕ. Let us now calculate the expected income of a trained worker in the second period. With probability (1-d) the worker will still be alive. Conditional on this, he will stay with the firm with probability (1-d). As matching is completely random (see discussion below), with probability $d\phi$ he will be separated but matched with a firm who possesses the new technology. Thus his expected income in the second period[2] conditional on being alive is $[(1-d)+d\phi]\beta(y+\alpha)+d(1-\phi)\beta y$. The expected income of an untrained worker on the other hand is just βy. Thus the expected increase in the present value of the worker's earnings

$$SB=(1-d)(1-d+d\phi)\beta\alpha,$$

is the subsidy (bribe) that the worker is willing to pay to the firm in order to receive training.

On the other side of the market, the firm will receive the full marginal benefit of innovation, α, in the first period. However, in the second period it will have to pay higher wages (see footnote 2) and it may have to incur the training cost again if a new worker who is untrained arrives. Thus the expected present value of the increase in the firm's expected revenue in the second period, ΔR, is

$$\Delta R=(1-d)[(1-d+d\phi)(1-\beta)\alpha+d(1-\phi)(\alpha-c)]$$

where the first term on the right-hand side is the profit that the firm makes when it is together with a trained worker. The second term is its net profit when matched with an untrained worker, which has probability $d(1-\phi)$ since a proportion ϕ of firms adopted the innovation and trained their workers in the first period and hence a proportion $1-\phi$ of newly unemployed workers will be untrained. Innovation will thus be beneficial if the sum of the incremental return in the first period, α; the increase in the expected return in the second period, ΔR; and the training subsidy paid by the worker, SB, is greater than the cost, $\delta+c$. Collecting terms we obtain the following

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[2] The assumption that even if the worker stays with the firm, he receives w^t is a convenient normalization as the worker pays the expected value of this increased salary back to the firm in form of a training/innovation subsidy.

condition for innovation to be profitable

$$(2-d)\alpha \geq \delta + c + d(1-d)(1-\phi)c \tag{1}$$

Inspection of (1) leads to a number of interesting observations;

(i) There are insufficient incentives to innovate relative to the competitive/first-best outcome (given by "innovate iff $(2\text{-d})\alpha \geq \delta + c$"). The underlying reason is the inability of the firm and the worker to capture *all* the future benefits created by this innovation and training decision. Some of the future benefits accrue to the *future* employer of the worker. Underpinning this and all the results of this paper are the following three assumptions: (a) the innovation in question necessitates upgrading the worker's general human capital which increases his future as well as current productivity; (b) there exists a positive probability that the worker will not be together with the same firm in the future; (c) labor market frictions prevent the competitive allocation of workers, thus imply that workers expect to receive less than their marginal product. The crucial ingredient here is the randomness of matching. This implies that we cannot make sure that *the "right" workers end-up with the "right" firms*. Naturally in practice, trained workers may refuse to accept a job in which their skills are not being put to use. However, this would not change our results as when trained workers meet a firm without the new technology, they will continue to search and incur a search cost and therefore they will be receiving less than their *full marginal product* because of the search cost. As a result workers will care about the proportion of firms with the new technology and similarly firms will care about the human capital of the pool of workers. (Although the main externality analyzed here remains, a number of different issues arise when we allow workers to change partners and model search costs explicitly).

It is instructive at this stage to contemplate what arrangements would restore first-best in this economy. The required subsidy is certainly not one between the worker and its current employer (such as an exit fee), because all the spill-overs within this relationship are being taken care of by the existing training subsidy, SB[3]. By its training decision the firm is not increasing the return to the worker, but rather, that of the worker's *future* employer. Therefore, a payment

[3] It can also be noted that if the worker did not die but just moved to another sector, region or firm because of some exogenous reason (e.g. he is no longer productive with this firm or learned that the match specific surplus is small in a Jovanovic (1979) type setting), a contract specifying an exit fee can be written. However it can easily be seen that this will not change anything. The value of the exit fee needs to be subtracted from the subsidy, SB and added to ΔR and these two will exactly cancel out. The crucial point here is that the quit is not because of a high wage offer but because it is optimal (or unavoidable) for the worker to move.

from the future employer of the worker to his current employer is required[4]. Since such a subsidy cannot be easily implemented by the market, decentralized equilibrium will often fail to internalize this externality. Transfer markets for sportsmen provide an instance where the market implements such a scheme; the new team has to make a payment to the old club of the player. The crucial ingredient for such an arrangement is the existence of two separate job markets, one for trained and one for untrained workers[5]. However as long as the probability of a match between a firm with the new technology and a worker with high human capital depends on the abundance of these types, the effects suggested in this paper will be present.

(ii) The decision rule summarized in (1) can be interpreted as "invest iff the benefit is greater than the *effective cost* of innovation". The effective cost in a competitive labor market is equal to the actual cost, $\delta+c$. However, with frictions, we have the additional term, $d(1-d)(1-\phi)c$ because the firm anticipates that it may have to incur the cost of training in the future. Here we can also see that this externality leads to natural *multiplier effects* since, as one firm invests, it reduces the effective costs to other firms and they become more willing to invest. Thus a shock that makes investment more productive for a group of firms will also increase the profitability of investment for, and innovation activity by, other firms.

(iii) Incentives to innovate are increasing in ϕ since the effective cost of innovation is decreasing in this variable. As more firms innovate, the pool of trained workers grows and it becomes more profitable for each firm to innovate. Therefore the interactions in the labor market create thick market externalities.

(iv) Although the source of the externality is that workers (and firms) do not receive their full marginal products, the bargaining power, β, does not affect the effective cost of training. This is because of our special set-up. In our model a trained worker loses $(1-\beta)\alpha$ when he meets a firm with the new technology, however this is exactly equal to the amount that the firm with the new technology extracts when it meets a trained worker. However, the worker also receives less

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[4] The fact that the externality is not between the worker and the firm but between them and the future employer of the worker distinguishes this effect from the one discussed by Grout (1984) where bargaining only over wages may lead to underinvestment because higher investment increases the quasi-rents obtained by the workers. However such a problem can be solved if binding wage contracts can be written or workers can subsidize the firm for the investment it undertakes. Our externality does not require these restrictions on bilateral contracting opportunities.

[5] Saint-Paul (1993) and Burdett and Smith (1993) discuss returns to education in the presence of such market segmentation.

than his marginal product because with a positive probability he ends-up with a firm who cannot make good use of his skill. If the worker and the firm face different probabilities of death, bargaining power enters the decision rule, but its effect is of second-order. However, bargaining becomes more important if workers have to make their human capital decisions before meeting a firm.

We can now summarize the main result of our discussion;

Proposition 0:
If $\delta + c < (2\text{-d})\alpha < \delta + c + d(1\text{-d})c$, there exist two pure strategy symmetric Nash equilibria in this economy; one in which all firms adopt the innovation in period 1 and train their workers and the other in which no innovation nor training take place.

Returning to (ii) above, the intuition of our result can be given as follows; when other firms do not invest, the effective cost of training is prohibitively high for the firm as it anticipates that the workforce, from which its future workers come, will be low human capital. This is line with the view that certain less developed countries do not attract sufficient investment because their workforce is untrained and unskilled (a similar argument is also used for protecting infant industries; for a discussion see Johnson (1971) or Corden (1974)). However, as firms who adopt the innovation would often find it profitable to train their new workers, the general level of training in the workforce will be endogenous and in order to analyze this problem fully we need a dynamic model which we develop in the next section.

Finally, since the equilibrium in which the innovation is not adopted is Pareto inferior, welfare can be improved in this economy by subsidizing training or the adoption of the innovation[6]. Training and re-training subsidies are quite common in many countries and our model suggests a mechanism that justifies these but also shows that the need for training subsidies may vary between sectors. For instance, industries with high d or a high degree of heterogeneity (which would imply that there will always exist some firms who would not adopt the innovation, thus $\phi < 1$) require to be targeted for such subsidies.

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[6] Alternatively, if the innovation is being supplied by a monopolist, the monopolist may try to offer a discount in order to entice firms into adopting the innovation. It is often observed that new softwares offer discounts at early stages which is consistent with such a story. However, such action by a monopolist will not in general eliminate the externalities in our model.

b) Empirical Relevance

Since this paper is proposing a new externality affecting investment decisions, we have to ask whether this mechanism is empirically plausible and relevant. First it is plausible to assume that there are mobility costs in labor markets, in particular for high human capital. Most workers spend a long time without a job after a separation (e.g., Devine and Kiefer (1991) or Topel and Ward (1992)) and there also exist adjustment and transactions costs in changing jobs. Firms also spend considerable resources in hiring activities (Barron et al (1985)). Further, the empirical literature on job reallocation and gross worker flows is indicative of significant uncertainty surrounding the future of employment relations. As a rough measure, we can use an infinite horizon version of equation (1) with discounting which would imply that the effective cost of innovation is higher by $\frac{(1-d)dc}{R+d}$ when other firms do not invest, where R is the real annual interest rate (which is the relevant discount rate since capital markets are perfect). Given that monthly separation rates are as high 4.5% (see Leonard (1987), Blanchard and Diamond (1990)) or annual separations run close to 50% a year in US manufacturing (OECD (1986)), a conservative estimate of d would be around .20, also bearing in mind that trained workers have lower turnover than untrained ones (Mincer (1988)). taking, the annual real interest rate to b 4%, this would imply that the cost of training is 66% higher when other firms do not train their workers, which is an economically significant magnitude.

Our mechanism is also consistent with a number of findings in the training literature. For instance that workers who switch jobs in general experience slower wage growth than those who stay despite the moving premium (Mincer (1988)) and that workers do not pay for their general training fully (Bishop (1991)). Both of these are predicted by our model as workers receive less than their marginal product once they change jobs. However, these findings can also be explained by interpreting all training as a combination of general and firm-specific training, hence cannot be used to conclusively endorse our mechanism.

An alternative line of attack is to investigate whether there exist cases in which training costs played a crucial role in adoption decisions and whether thick market externalities were important in this process. With this aim in mind, we turn to the adoption of software engineering innovations. Fichman and Kemerer (1993) discuss three innovations; SMs (Structured Methodologies), 4GLs (Production Fourth Generation Languages), and RDBs (Relational Database Management Systems). Of these innovations only the last one was adopted although all of them were initially thought to be very promising. SMs in particular were hailed as "a revolution in software engineering" and had the capacity to bring "significant reduction in

systems maintenance costs" (Fichman and Kemerer (1993)). However, very few companies put them to practice and they were soon abandoned. The only significant disadvantage of SMs seems to be high training costs. Although the benefits appear to be potentially large, free-rider effects (as discussed in Section 5) may have been the key. Very few companies ended-up adopting this innovation which would have increased the effective cost to those few who went ahead. Yet other explanations can also be offered to account for the failure of SMs; two obvious candidates that are often put forward are network-externalities[7] and learning from others' experience. However there are no obvious reasons why technological network externalities should be significant since standardization does not seem to be as much an issue as in communication systems. Also since initial expectations were very high and the physical investment required was not very expensive (though the training costs were high), waiting to learn from others' experience may not be a very good explanation either. Turning to 4GLs, these were expected to bring "ten-to-one improvements in programming productivity" compared to COBOL and other 3GLs. Additionally these new techniques did not have compatibility problems when switching from 3GLs and the actual training costs were not high. Again, the two conventional explanations do not appear satisfactory. There was no need for networking; different companies used different programming languages before the arrival of 4GLs and as the set-up and actual training costs were low, waiting should not have been an important deterrent. However, many different versions of 4GLs arrived in the market and each different language required additional training, thus the effective cost of training was much higher than the actual cost because new employees who would arrive from companies that adopted other languages would have to be re-trained. On the other hand, RDBs that had a very similar background to 4GLs and SMs were very quickly adopted and became the dominant technology. This is despite the fact that RDBs required very expensive software and training, thus the response of the whole industry seems to be the key here. All three stories are consistent with our theory, while not easily explained by the alternatives.

It is also possible to obtain historical examples. An attractive one for our purpose is the QWERTY keyboard discussed by David (1985). This is obviously an inferior technology adopted

[7] It can be argued that our externality is a form of network externality, as coordination is also a key issue in our mechanism. Although this is partly true, our mechanism is explicitly derived from microfoundations and interactions in the labor market. With network externalities, we refer to those technological in nature (such as standardization in communication). For an analysis of network externalities, Katz and Shapiro (1986).

at the time to slow down typists so as not to jam the typewriters. Also, there was no uncertainty about the success of alternative keyboards and no need to standardize since all that mattered was the final output. However, QWERTY has survived to the present. Although there is no need to standardize the output and the actual cost of training is relatively low, the effective cost would be very high if only a few companies changed their keyboards.

Thus a number of different pieces of empirical evidence accord well with our story, suggesting that it is empirically relevant and plausible while its exact quantitative importance obviously requires much more careful empirical investigation.

3) The Basic Dynamic Model

Consider a dynamic analogue of the economy of the last section. This economy consists of a continuum of risk-neutral and profit-maximizing firms with measure F, and a continuum of workers with measure 1. Each firm is assumed to employ a large number of workers (thus F is small relative to 1). At the firm level, there are constant returns to scale and each worker produces goods worth $y+b$. For simplicity and in contrast to the previous section, we assume that workers have no bargaining power ($\beta=0$). As it can be seen from the previous section, this is not an assumption that changes our results, but it simplifies the analysis considerably as we do not have to follow the time path of wages for trained and untrained workers. Each worker will therefore be paid a wage rate equal to the opportunity cost of time which is assumed to be constant and equal to b. This also implies that the firm will pay for training as the worker is receiving none of the benefits.

We denote the number of workers that a firm employs at time t by n(t). Instead of random shocks to workers and firms, we assume a constant exogenous probability of involuntary separation for each pair such that at every instant sn(t) workers leave the firm and join the unemployment pool. The firm receives λ applicants from the unemployed. As unemployment is constant in this section, λ too is constant. We assume that new workers can start production as soon as they arrive thus the firm does not lose any output in the turnover process. The employment of each firm follows the law of motion

$$n'(t)=\lambda-sn(t) \tag{2}$$

where $n'(t)$ is derivative of $n(t)$ with respect to time. The firm accepts all the applicants[8] since $y>0$ and workers accept all job offers as they always receive the same wage rate. In steady state the employment level of a typical firm will be constant at $n(t)=n=\lambda/s$. In what follows our economy will start from a point of steady state. We will later discuss how both the number of firms in the market and the number of workers per firm can be endogenized.

At time $t=0$ we are in a steady state with $n(t)=n\equiv\lambda/s$, an innovation opportunity becomes available. This innovation will raise the product per worker by α for all future periods, but the firm needs to install the new technology at a cost δ and to train the existing workforce at a cost c per worker. As in the previous section, there are no technological or aggregate demand externalities and the incremental revenue per firm as a result of this innovation is independent of the number of firms.

To proceed with the analysis, let the value of the firm at time t be denoted by $J(t)$ when it innovates and by $V(t)$ when it does not. Each period, (1-s) proportion of the workforce from the previous period remains with the firm and λ new workers arrive. Since without the new technology all workers are the same, $V(t)$ is given by the following asset value equation

$$rV(t)-V'(t)=(1-s)n(t)y+\lambda y \tag{3}$$

where r is the discount rate (remember that output per worker is $y+b$ so that the wage bill $n(t)b$ is already subtracted). However, when $n'(t)=0$ and $n(t)=n$, we will have $V'(t)=0$ as there is no change in the return to a firm without the new technology. Therefore $V=ny/r$.

Two issues arise when we analyze returns from innovation. First, returns will be time varying as the number of trained unemployed workers will not be constant (i.e. the general skill level of the workforce will be changing endogenously). Second, the firm needs to choose a strategy which will determine what it will do when untrained workers apply. The firm will naturally accept all applicants irrespective of their level of training (as there is no opportunity cost to doing so). We further assume that $\frac{\alpha}{r+s}>c$ where c is the cost of training a newly arriving untrained worker (when this assumption is not satisfied, innovation will never be profitable, see Lemma 3.1). This makes it profitable to train all newly arriving untrained workers. However there is another aspect to waiting; when to innovate? This we will consider in section 5 and until then firms are only allowed to adopt the innovation immediately after it

[8] The firm would like to expand as much as possible, however labor market frictions prevent this. These frictions also allow firms with different productivity levels to coexist despite firm-level constant returns.

becomes available and once they carry out the investment, they will train the workers.

The cost of adopting the innovation is δ. The total initial cost is δ+nc as the firm has to train its existing workforce. On the revenue side, the firm receives a net return equal to (α+y) from each worker who has not quit, thus a total of (1-s)n(t). As it is profitable to train the untrained workers, the firm also receives λ(y+α) from workers arriving this period but incurs the cost c for those who are untrained. In order to monitor changes in future training costs, we define q(t) as the proportion of untrained workers in the unemployment pool. Thus q(t) is one measure of the general skill level of the economy. However, it is not sufficient to keep track of q(t) only, because employed workers may also be trained or untrained. Firms that adopt the innovation will train all their workers, thus we only need to determine the skill composition of the workers of firms who did not innovate. We denote the proportion of trained workers in a firm that did not innovate by m(t)[9]. The economy starts from a point of steady state, therefore λ=ns which enables us to rewrite the value of an innovating firm as:

$$rJ(t)-J'(t)=n(\alpha+y)-nsc(1-q(t)) \tag{4}$$

Intuitively, a firm that has adopted the innovation will always train all its workers, therefore in steady state the revenue of such a firm will always be equal to n(α+y). However, its costs will vary depending on the training level of the new workers. In steady state ns workers will arrive from unemployment; by definition a proportion (1-q(t)) of these will be untrained and the firm has to incur nsc(1-q(t)). As new workers only come from unemployment, m(t) does not enter (4) directly but influences the evolution of q(t).

In other words, q(t) and m(t) will vary over time. The law of motion of q(t) will depend on the proportion of firms that adopt the innovation, ϕ, and on the probability that an unemployed worker finds a job, p and will be given by (see the derivation of equation (5) in the appendix)[10];

$$q'(t)=p(\phi(t)+(1-\phi(t))m(t)-q(t)) \tag{5}$$

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[9] This is again related to our assumption that there does not exist market segmentation depending on skill level, thus trained workers can be matched with firms who cannot make best use of their skills.

[10] m(t) and ϕ(t) will become more important in section 5. Since in this section it is assumed that innovation can only be adopted as soon as it becomes available, ϕ(t) is constant over time and m(t) is constant in symmetric equilibria.

In steady state, entry into and exit from unemployment occur at the rate p. Of the workers who join the unemployment pool, $\phi(t)$ come from firms that have adopted the innovation and are therefore trained. A proportion $(1-\phi(t))$ come from firms that did not innovate and a proportion m(t) of those are trained. Also a proportion q(t) of the workers who exit unemployment are trained which explains the last term. It is useful to note that p is assumed equal across trained and untrained workers. Relaxing this assumption would not change our results, but would complicate the mathematics considerably.

Finally, the law of motion of m(t) is given as follows;

$$m'(t)=s(q(t)-m(t)) \tag{6}$$

At each instant, workers arrive at the rate s and a proportion q(t) of those are trained. They also leave the firm at the rate s and a proportion m(t) of those are trained. It will be profitable for a firm to invest if the net present value of investing is positive; i.e. if $J(0)-\delta-nc$, the net return of investment, is greater than V(0). To determine this we need to solve the law of motion of J(t), q(t) and m(t) jointly. Since in this section we are only interested in symmetric equilibria, we only check $\phi(t)=1$ and $\phi(t)=0$.

Lemma 3.1:
For values of the productivity of the new technology, $\alpha \geq \alpha_0 \equiv \frac{rsc}{p+r}+\frac{r\delta}{n}+rc$, it is profitable to invest when all other firms in the economy are doing so.

As with all the lemmas, the proof of Lemma 3.1 is in the appendix.

The terms that constitute α_0 can be intuitively explained; $r(\delta/n+c)$ is the flow cost of innovation if no workers leave. However, the firm also considers $rsc/(p+r)$, a "tax" imposed on the firm by workers who leave. Innovation is more likely, the lower is c, δ, s and r and the larger is n. The latter effect is due to the fact that, although the training cost has to be incurred for each worker, δ is the fixed cost of innovation and once the innovation is adopted all workers will have higher productivity. This builds a type of scale economies into the innovation process. The parameters s and p enter the decision rule because, although they do not influence the actual cost, $(\delta+nc)$, they are crucial for the effective cost of innovation.

Now consider how incentives to innovate differ when other firms do not invest. The "tax" imposed on the innovating firms will be higher because the pool of untrained workers is larger.

Lemma 3.2:

For values of the productivity of the new technology, $\alpha \le \alpha_1 \equiv sc + \frac{r\delta}{n} + rc$, it is optimal not to invest when no other firm invests.

As $\alpha_0 < \alpha_1$, we can establish the main result of this section:

Proposition 1:

For values of α such that $\alpha_0 \le \alpha < \alpha_1$, there exist two pure strategy Symmetric Nash Equilibria, one in which all firms adopt the innovation and the other in which no firm invests.

The intuition of this proposition is the same as the result we obtained in the previous section. The effective cost of innovation depends on the average quality of the human capital of the workers the firm expects to receive in the future. The lower is this average quality, the higher is the effective cost. On the other hand, the more firms invest, the higher is the quality of this human capital and the more willing is each individual firm to innovate. As in the previous section, this interaction also leads to multiplier effects in response to changes in costs or productivity.

In what follows we will sometimes refer to the equilibria of Proposition 1 as "good" and "bad" or equilibria supported by favorable or unfavorable conjectures. These names are appropriate since there is a clear Pareto ranking between these equilibria. Also the "good" equilibrium can be thought of as having a higher growth rate because an economy in the "good" equilibrium undertakes more investment than one in the "bad" equilibrium[11]. In particular suppose that α is drawn from a distribution $H(\alpha)$ with support $[0, \alpha_{max}]$. It follows that the probability of investment in the good equilibrium is $\Theta_0 = 1 - H(\alpha_0)$, and in the "bad" equilibrium, is $\Theta_1 = 1 - H(\alpha_1)$. The probability of investment can be thought as a measure of the economy's growth potential implying that the "good" equilibrium has higher growth potential since $\Theta_0 > \Theta_1$.

Not only is there a multiplicity of equilibria under plausible circumstances (and without nonlinearities and/or externalities in technology), but also the multiplicity of equilibria illustrates

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[11] If generalized with repeated arrivals of innovations, the "good" equilibrium would have a higher growth rate. However repeated arrivals introduce mathematical difficulties as when the second innovation arrives, the economy is out of the steady state. Naturally with one innovation opportunity, as we have here, the growth effect will be negligible. We also obtain similar results when firms differ in their adoption costs, but the expressions become more involved (details are available upon request).

a phenomenon that is thought to be important by many economists; as physical and human capital are complements in most production processes, a predominantly low skilled workforce can be thought to deter investment. However this intuition is not true when the labor market is competitive because workers will always be paid the marginal product of their human capital and firms will have no reason to care about the general skill level of the workforce (as long as all the skill levels are traded). Proposition 1 shows how labor market imperfections can lead to such a result and formalizes this intuition; in the "bad" equilibrium the reason why no firm adopts the innovation is that they anticipate their future workers to be predominantly untrained. However, it also asserts that this state may have endogenously arisen because firms do not invest. Thus the "bad" equilibrium can be seen as an "underskilling" trap.

4) Closing the Model

So far F, n, p and λ have been treated as exogenously given. If we endogenize these variables, some new insights about the interaction of labor markets and the innovation process can be obtained. Let us denote the measure of unemployed workers in this economy by U. Since the labor force is normalized to 1, this also is the unemployment rate. As we are dealing with a steady state, U will be constant. The rate at which an unemployed worker finds employment, p, is defined as equal to the flow into employment over the stock of unemployment, thus $p=\lambda F/U$ will be constant too. The following results can then be stated;

Proposition 2:

The value of a firm that innovates, J(t), is decreasing in the unemployment rate of the economy.

Proposition 3:

The probability of innovation in the favorable equilibrium, Θ_0, is decreasing in the unemployment rate.

Proofs of these two propositions can be found in the appendix.

The mechanism that leads to this result is that the unemployed workers are by definition

untrained[12]. Therefore, the higher is unemployment, the higher is the effective cost of innovation. The end result, a negative relationship between unemployment and growth, is similar to that of Pissarides (1990) and Aghion and Howitt (1992) where higher growth leads to lower unemployment through higher job creation. But here, the causation runs from unemployment to growth. An autonomous increase in unemployment will lead to slower growth in our model but not in the above mentioned ones. This is in line Habakkuk's (1962) famous thesis that tight labor markets lead to faster growth, which receives some casual empirical support. However, in contrast to Habakkuk's interpretation that most technologies are labor saving and that high wages in tight labor markets are the driving force leading to innovations which seems not accord well with what we know about the nature of most inventions (see MacLeod (1988), Mokyr (1990)), our theory maintains that innovations are complementary to labor, but we obtain this result because tight labor markets provide more incentives for workers and firms to invest.

More generally, p, the probability that a worker finds a job, will be a function of the number of firms as well as the number of unemployed workers in the market. Using the insight of search equilibrium models (e.g. Pissarides (1990)), we can endogenize both the size of each firm and the unemployment rate in this economy. However we are most interested in the determination of unemployment and innovation incentives so we will adopt a number of simplifying assumptions and keep the size of each firm constant. Since out of a population of 1, nF workers are employed, the unemployment rate in this economy, U, is given by

$$U = 1 - nF \tag{7}$$

This also implies that as an additional firm becomes active, unemployment is reduced by n.

We will also assume that there is a fixed cost of entry for each firm, k(F). This cost is a function of the number of firms in the market which will enable us to capture congestion effects. These effects arise in search models because as more firms enter, the market becomes "crowded" and the probability that a given vacancy will be filled falls, thus reducing expected profits from opening a new vacancy. Our desire to keep the firm size constant in order simplify the analysis makes this unattractive for us. Instead we assume that $k'(F) > 0$ to incorporate these congestion effects. As more firms enter the cost of opening a new firm increases (e.g. Howitt and McAfee (1987)). We also assume that the market cannot support more than a certain number of firms, F^{MAX} thus $\lim_{F \to F^{max}} k(F) = \infty$. Also like Pissarides (1985,1990) we will make use of

[12] It can easily be seen that even if unemployed workers had access to an educational institution that could offer them training they would be willing to pay less for it than employed workers and the qualitative results would remain unchanged.

a zero profit condition in order to close the model. However Pissarides assumes that there never exists profit opportunities in the market, thus the number of vacancies is a jump variable that instantaneously adjusts to satisfy a zero profit condition. For our purpose, it makes more sense for firms to decide whether to enter or not at some date and make the initial investment but if the productivity of the new technology is higher than anticipated, these firms will be able to obtain some of the rent.

We thus assume that all entry takes place at t=-T. Firms know that a new technology will become available at t=0. The productivity of this innovation is not known ex ante except for the fact that it will be drawn from a distribution H(α). We will be looking for the Rational Expectations Equilibrium of this economy, thus firms know which equilibrium will be played once the productivity of the new technology is revealed. We will show that even once we condition on firms' conjectures about which equilibrium will be played, there will exist an additional strategic complementarity: as more firms enter, entry becomes more profitable.

The zero profit condition will take the form of

$$k(F)=\frac{ny}{r}+e^{-rT}\{\int_{\alpha_c(F)}^{\alpha^{max}}(J(0,\alpha,F)-\delta-nc-\frac{ny}{r})dH(\alpha)\} \tag{8}$$

The right-hand side of this equation can be explained as follows: the firm receives the flow ny from t=-T to 0. Thereafter it can refuse to adopt the innovation in which case it continues to receive ny. The present value of this profit flow, evaluated at t=-T, is ny/r. Alternatively if the productivity increment, α, is greater the cut-off productivity level, α_c, the firm will adopt the innovation, obtaining J(0,α,F), incurring the innovation and training cost δ+nc, and losing the flow income of the old technology. As we do not know the realization of α, we need to take expectations conditional on $\alpha \geq \alpha_c$(F) which is what integration does. Note that although n does not depend on the number of firms, the probability that an unemployed worker is matched with a firm, p, does and via this, the cut-off level of productivity, α_c(F) and the flow profits, J(0,α,F) depend on F too.

First, in (8) there can be two different cut-off points for the adoption of this innovation conditional upon a given number of firms (i.e. "good" versus "bad" equilibrium). When all firms believe they are in the "bad" equilibrium, the number of firms in the market will be determined by

$$k(F)=\frac{ny}{r}+e^{-rT}\int_{sc+\frac{r\delta}{n}+rc}^{\alpha^{\max}}\left(\frac{n(\alpha+y)}{r}-\frac{nsc}{p(F)+r}-\delta-nc-\frac{ny}{y}\right)dH(\alpha)\equiv\pi_b(F) \tag{9}$$

where p depends upon F through equations (4) and (5). The RHS of this equation is everywhere increasing by assumption. The LHS is also increasing since as more firms enter, unemployment falls, p increases and profitability of innovation increases. Differentiating $\pi_b(F)$ we obtain

$$\pi_b'(F)=e^{-rT}\int_{sc+\frac{r\delta}{n}+rc}^{\alpha^{\max}}\frac{nsc}{(p+r)^2}\times\left\{\frac{ns}{1-nF}+\frac{n^2sF}{(1-nF)^2}\right\}dH(\alpha) \tag{10}$$

which is also an everywhere increasing function. These curves can thus intersect more than once as Figure 1 illustrates. In particular, if k(0) is greater than $\pi_b(0)$, there will exist an equilibrium in which no firm is active but two additional equilibria with positive activity may also exist. Note that all these equilibria are conditional upon the "bad" equilibrium being played once the firms enter. Alternatively firms may expect to be in the favorable equilibrium, in which case the equilibrium condition becomes

$$k(F)=\frac{ny}{r}+e^{-rT}\int_{\frac{rsc}{p(F)+r}+\frac{r\delta}{n}+rc}^{\alpha^{\max}}\left(\frac{n(\alpha+y)}{r}-\frac{nsc}{p(F)+r}-\delta-nc-\frac{ny}{r}\right)dH(\alpha)\equiv\pi_g(F) \tag{11}$$

We can see that similar effects are present here as well but there is also the added effect that the cut-off productivity level is a function of the number of active firms. This effect further strengthens the strategic complementarity that is created by entry decisions.

In general, the number of firms in this economy, n, will also depend on F and as more firms enter, λ, the number of applicants per firm will fall and the steady state equilibrium size of each firm will shrink. This is the effect of congestion we tried to capture with k(F). Also note that if further entry reduces the equilibrium size of firms, it will also reduce innovation incentives through the scale economies discussed earlier. Even when we model the congestion effect explicitly in this way, it cannot be analytically determined which effect will dominate.

In this context it is instructive to return to the relationship between investment and unemployment. As emphasized above, higher unemployment leads to lower investment incentives and hence to slower growth. Yet Aghion and Howitt (1992) detect an inverse 'U' shaped relationship between growth and unemployment (i.e. a low level of unemployment can be associated with a low as well as a high level of growth) in a cross-country regression using OECD data, while Bean and Pissarides (1992) question the existence of any well-defined relationship. This lack of negative relationship between unemployment and long-run growth in

the data poses a potential challenge to one of the predictions of our model. However, it should first be remembered that growth and unemployment are both endogenously determined and while high unemployment may lead to slower growth, high growth may also lead to high unemployment (e.g. due to the creative destruction effects of Aghion and Howitt (1992)), thus raw correlations may not be too informative. Further, the endogeneity of entry decisions in our model serves to muddy the waters via the level of activity and the size of firms in the market. Countries will differ in their fundamentals, i.e. s, δ, c, $H(\alpha)$ and their matching technology, which will lead to different levels of activity in their economies. As activity, i.e. F, increases, unemployment falls but each firm also becomes smaller, thus leading to lower investment incentives through the scale economies. Hence a low level of unemployment can be associated with low growth. On the other hand as F increases and unemployment falls, p (the exit probability from unemployment) rises thus increasing the incentives to innovate (i.e. $\pi_i'(F)>0$ for $i=b,g$). High growth can therefore be associated with low unemployment. Yet, note that the causality in our case is very different from that of Aghion and Howitt. In their model, the form of technical progress may lead to higher (or lower) unemployment. Thus the driving force of their model is technical progress (or growth). In contrast in our model the "driving force" is the active number of firms which influences unemployment and through this, the investment incentives of the firms (and the growth rate of the economy). It is often argued that the organization of the labor market will have implications for the growth performance of an economy (going back at least to Habakkuk (1962) and perhaps as far back as Marx). The mechanism just identified, running from unemployment to growth, provides a route through which such effects will operate. This analysis also generates certain testable implications different from Aghion and Howitt (1992)'s inverse U-shaped relationship. In particular, if we look at the relationship between unemployment and growth, using sectoral data and controlling for sector/region specific variables (such as average firm size, training costs, general skill level of the workforce etc), there should be a clear inverse relationship. However, when we do not control for these variables, the relationship may no longer be negative.

Finally, when our model is closed, an interesting complementarity between invention and innovation activity is obtained due to the multiplier effects discussed in the previous sections. An improvement in the invention performance of the economy can be captured by a right-wards shift of $H(\alpha)$, the distribution function of the innovation's productivity. Now consider local comparative statics (i.e. we do not shift from one equilibrium to another, thus in Figure 1 we move from point A to point B), F, the number of active firms, will increase and unemployment

the cut-off level for innovation will fall. This complementarity implies that a shock which leads to growth when drawn from a favorable distribution may not lead to growth when drawn from a less favorable distribution (i.e., incremental productivity, α, can be greater than the new cut-off level, α_B, but below the old cut-off level, α_A). Therefore in economies with better innovation prospects, mediocre investment opportunities will be exploited while the same is not true for economies that face an unfavorable distribution for new technologies. This mechanism would further agglomerate initial technological differences between economies.

5) Timing of Innovation Activity and Free-Rider Effects

In this section the basic model of section 3 is modified in one respect. Firms are allowed to choose the timing of their adoption after they receive the opportunity rather than being faced with a "now or never" decision as in the previous sections. The assumptions that the training cost, c, the innovation cost, δ, and the marginal productivity of innovation, α, are equal across all firms are maintained. Since firms have a timing decision, we ask when it will be profitable to adopt the innovation. If the answer is $t=\infty$, this corresponds to the innovation never being adopted. With this aim in mind, we write the payoff to adopting at time t an innovation that becomes available at time $\tau=0$;

$$W(t)=(1-e^{-rt})\frac{ny}{r}+e^{-rt}\,[J(t)-\delta-(1-m(t))nc] \tag{12}$$

Intuitively for the first t periods the firm gets the return of a firm that has not innovated which is the first term in (12). At time t the firm incurs the innovation cost δ but also has to train the workers. As a proportion m(t) of the workers are already trained, it only incurs the cost (1-m(t))nc and it receives J(t). Discounting this to time $\tau=0$, the second term in (12) is obtained. It will obviously be optimal to innovate at t only if $W'(t)=0$ (or when $W'(0)\leq 0$). In particular in the case where W'(0) is positive, waiting will be profitable at t=0 when the innovation opportunity is received.

Lemma 5.1:

If

$$\alpha<\alpha_1=sc+\frac{r\delta}{n}+rc \tag{13}$$

it is not profitable for a firm to invest alone.

The intuition of this Lemma is an extension of our results in sections 2 and 3. We know that the effective cost of innovation is lower when more firms train their workers. By implication, the first firm to innovate will face a high effective cost as no other firm has yet innovated. Therefore, all other things being equal, the firm would prefer to wait for others in order to reduce its effective costs. However, by waiting the firm is delaying the increase in its revenue which obviously has a cost. If α is not too high, i.e. if (13) is satisfied, the first effect will dominate and the firm will prefer to wait for others to innovate[13]. Also note that (13) is the same as condition in Lemma 3.2; when (13) does not hold, we know from Lemma 3.2 that each firm will find it profitable to invest even if it believes other firms will not be investing. However when (13) is satisfied, firms do not want to go alone and they will prefer to wait for others. Alternatively we can view firms as trying to free-ride on others. Waiting is profitable because as other firms invest the effective cost of training is reduced. Yet, by the same reasoning those firms that adopt first would bear a disproportionate share of the burden, thus they do not want to move first.

Next we can ask what the form of the equilibrium will be when (13) is satisfied. Without the option to wait, Proposition 1 tells us that if $\alpha \geq \alpha_0$, there will exist two symmetric equilibria. With the possibility of waiting, there exist other possibilities: all firms can adopt the innovation together at $\tau=0$ or a only a proportion of firms, indifferent between adopting now and delaying, go first and the rest follows slowly. However, Proposition 4 shows that when (13) is satisfied, even when all other firms adopt the innovation, it will be profitable to wait, thus free-riding on the training costs. This implies that the favorable equilibrium in which the innovation is adopted disappears (even when $\alpha > \alpha_0$) and the ineffficiency of the previous sections is intensified (proof of Proposition 4 in the appendix).

Proposition 4:

When firms can delay adoption the innovation is never adopted in equilibrium if (13) is satisfied and all firms innovate together when (13) is not satisfied.

The intuition is given in terms of the free-rider effects. Firms would not like to be the first to innovate because the others would free-ride on the costs of training the workforce. But

[13] In practice there will naturally exist other considerations. For instance, in oligopolistic markets, the firm that innovates first may gain a competitive edge, e.g. Fudenberg et al (1983), Judd (1985) and Tirole (1990) for a review of the literature.

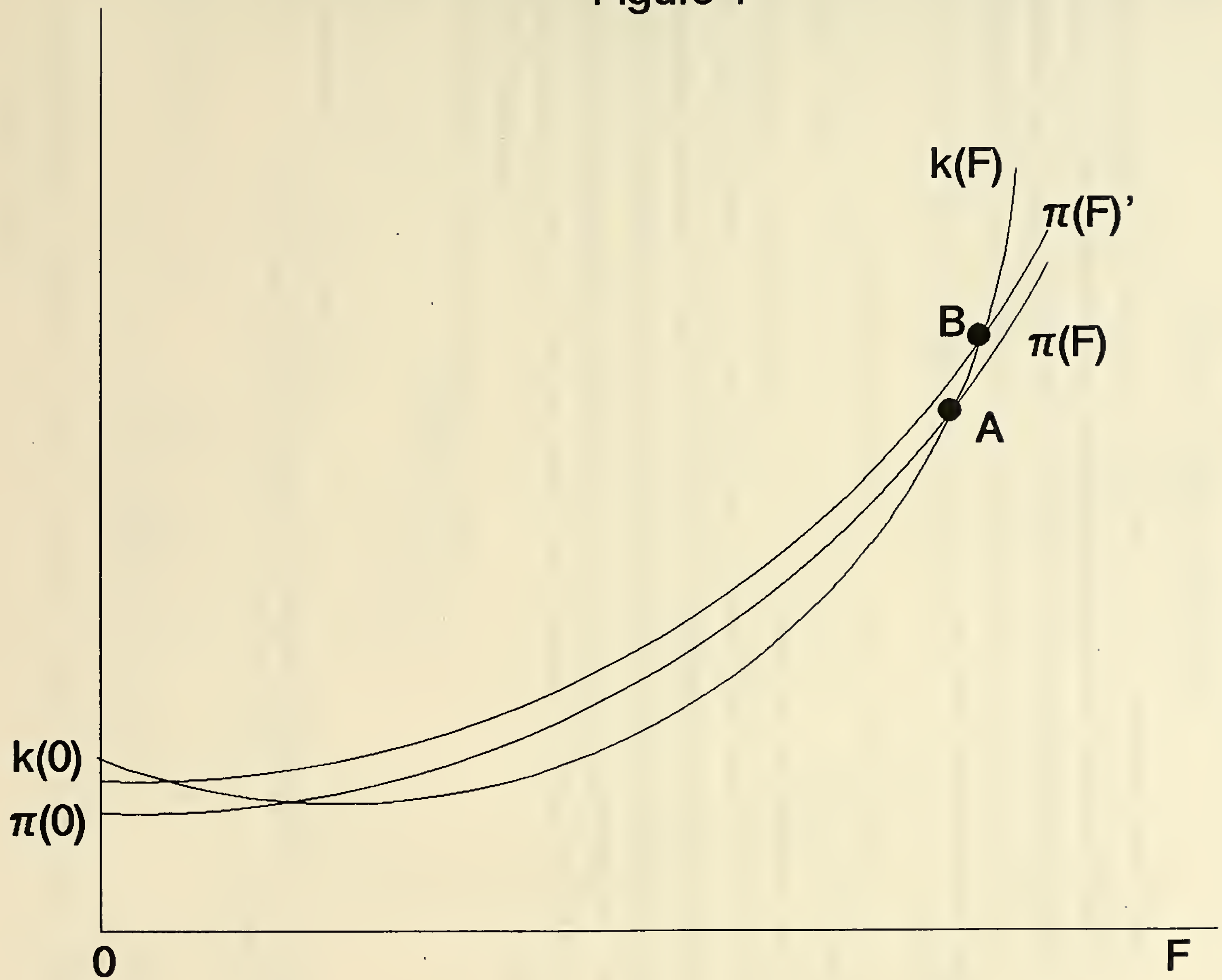
when all other firms invest, each firm would still like to free-ride and wait for the training level of the workforce to increase sufficiently. As a result no firm wants to move first which effectively blocks the innovation. Thus the flexibility to choose the timing creates free-rider effects and increases the inefficiency in the model by destroying the favorable equilibrium. This can also be interpreted as creating inertia in the economy in response to new technologies as no one wants to move which is in some respects similar to what Mokyr (1990) dubs as "resistance to technological progress" (though Mokyr's concept is much richer as it includes creative destruction effects).

6) Conclusion

The determination of investment and innovation incentives is an important research area and economists have been analyzing the effects of externalities in this process. This paper shows that labor market imperfections give rise to such externalities which may lead to multiple equilibria and free-rider effects. The model we consider can explain how skill shortages can endogenously arise making future investments less likely and also suggests some new linkages between unemployment and growth.

A major shortcoming of our analysis is that the wage determination process was largely ignored. Although it was informally argued that effects through wage determination would not change our results, it will be instructive to analyze this problem in more detail. Another area of future research that may be fruitful is to empirically test some of the results implied by this model, in particular those relating to the link between unemployment and innovation incentives. Although our model predicts that low unemployment can be associated with high or low growth, in contrast to Aghion and Howitt (1992) it implies that if we control for all other factors (such as the size of firms), lower unemployment will lead to higher growth. This cannot be easily tested on aggregate data but on sectoral or regional data, it should be possible to investigate whether, controlling for the size of firms and skill-level of the workforce as well as fixed effects, the level of unemployment affects investment and productivity growth adversely.

Figure 1



Appendix

Derivation of Equation (5):

Let Q(t) be the number of trained workers in the unemployment pool and M(t) the number of trained workers in a firm that has not innovated yet. Then

$$Q'(t) = nsF\phi(t) + M(t)sF(1-\phi(t)) - pQ(t) \tag{A1}$$

At each instant ns workers join the unemployment pool from each firm. ϕ(t)F firms have adopted the innovation thus their workers are trained. (1-ϕ(t))F have not adopted the innovation yet and only sM(t) trained workers become unemployed from these firms. Also each worker quits the unemployment pool at the rate p and thus pQ(t) trained workers exit the unemployment pool. Divide both sides of this equation by U which is constant; write M(t)=nm(t) and note that p=nsF/U. This gives us (5).

Proof of Lemma 3.1:

We are considering the case where ϕ(t)=1. Thus our system reduces to two variables q and J. The steady state value of q(t) is equal to 1, that of J(t) is n(α+y)/r. There is one predetermined variable, q, and one non-predetermined variable, J. If the rational expectations path is unique, one initial condition should enable us to determine the time path of both variables and there is one initial condition given by q(0)=0. A unique rational expectations equilibrium path exists as the roots of the problem are equal to r and -p from equations (4) and (5). The solution takes the form of

$$J(t) = \frac{nsc}{p+r}Ae^{-pt} + \frac{n(\alpha+y)}{r}$$
$$q(t) = Ae^{-pt} + 1 \tag{A2}$$

where A is a constant which we determine from the initial condition q(0)=0 as A=-1. It then follows that

$$J(t) = -\frac{nsc}{p+r}e^{-pt} + \frac{n(\alpha+y)}{r} \tag{A3}$$

and

$$J(0)=\frac{n(\alpha+y)}{r}-\frac{ncs}{p+r} \tag{A4}$$

Innovation is profitable if J(0)-δ-nc is greater than V(0), which gives us the condition $\alpha \geq \alpha_0$. QED

Proof of Lemma 3.2:

In this case unemployed workers are always untrained. As there is a continuum of firms, there will be no change in the proportion of trained workers in the unemployment pool and thus the return to investing is

$$rJ^{*}=n(y+\alpha)-nsc-n\sigma c \tag{A5}$$

The return from not innovating is again given by V above, thus it is profitable to invest if $\alpha \geq \alpha_1$. QED

Proof of Proposition 2:

The value of a firm that innovates, when all other firms invest, J(t), is given by (A3), is given which is strictly increasing in p. As we are in steady state with a constant number of firms and constant population, p is defined as equal to nsF/U. Thus p is decreasing in U. QED

Proof of Proposition 3:

Θ_0 is increasing in p and hence decreasing in U. QED

Proof of Lemma 5.1:

Differentiating (12) with respect to time

$$W'(t)=e^{-rt}\,[ny-rJ(t)+J'(t)+r\delta+rnc-rncm(t)+ncm'(t)] \tag{A7}$$

Substituting from (4), we get

$$e^{rt}\,W'(t)=-n\alpha+nsc+nrc+r\delta-nscq(t)-nrcm(t)+ncm'(t) \tag{A8}$$

We are considering a firm that will innovate alone which implies that m(0)=q(0)=0, thus m'(t)=0. Substituting these in

$$e^{rt} W'(t) = -n\alpha + nsc + n\sigma c + nrc + r\delta \tag{A9}$$

This is positive if (13) is satisfied and the firm prefers to wait. QED

Proof of Proposition 4:

Suppose (13) is satisfied. Can we have an equilibrium in which $\phi(t)$ firms adopt the innovation at time t? This can only be an equilibrium if $W'(t) \leq 0$. However, from (A8), $W'(t) > 0$ irrespective of the value of $\phi(t)$ as long as $m(t)=q(t)=0$. Therefore at $t=0$ and by a similar argument at all t, every firm would prefer to wait further and in equilibrium, the innovation will not adopted. If (13) is not satisfied, $W'(0) \leq 0$ and all firms find it profitable to adopt the innovation immediately at $t=0$. QED

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